TURBOCHARGER COMPRESSOR WITH NON-AXISYMMETRIC DESWIRL VANES

FIELD OF THE INVENTION

The present invention relates to two-stage radial compressors and to turbochargers that include such compressors, and more particularly relates to two-stage radial compressors wherein first-stage and second-stage impellers are arranged in a back-to-back fashion.

BACKGROUND OF THE INVENTION

A two-stage radial compressor with back-to-back impellers is described in U.S. Patent No. 6,062,028. In the embodiment shown in Figure 2 of the '028 patent, the pressurized air from the first-stage impeller passes through a diffuser into an interstage duct formed as a generally annular structure. From the interstage duct, the air passes through a row of deswirl vanes that reduce the tangential or swirl component of flow, and then enters the second-stage impeller. The pressurized air from the second-stage impeller goes into a second-stage volute that is concentrically arranged inside the interstage duct. To get the air out of the compressor housing assembly (which includes the interstage duct and second-stage volute), a discharge duct that leads from the second-stage volute out of the housing must penetrate through the interstage duct at one circumferential location of the duct. The presence of the discharge duct in the interstage duct causes the flow entering the deswirl vanes to be non-axisymmetric to a significant extent, because the fluid must flow around the outer surface of the discharge duct. Additionally, a significant amount of flow separation occurs as the flow comes off the discharge duct, and consequently substantial pressure losses are incurred.

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BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a cross-sectional view of a portion of a turbocharger in accordance with one embodiment of the present invention;

FIG. 2 is a three-dimensional representation of the flow path through the compressor in a "solid" form, illustrating the manner in which the discharge flow from the second-stage volute passes through the area of the interstage duct;

FIG. 3 is a perspective view of a portion of the compressor housing assembly of the turbocharger, showing the ring of deswirl vanes installed in the housing assembly;

FIG. 4 is a perspective view of the compressor housing shown with the outer wall of the interstage duct removed to reveal the leading-edge portion of a uniquely thick deswirl vane;

FIG. 5 is a front elevation of the compressor housing with the outer wall of the interstage duct removed to show the most upstream part of the leading-edge portion of the thick deswirl vane; and

FIG. 6 is a perspective view of a ring of non-axisymmetric deswirl vanes in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present inventions now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

The present invention is applicable to two-stage radial compressors having a back-to-back impeller arrangement such as shown in Figure 2 of the '028 patent referred to above. It has been found that in such compressors, the presence of the

discharge duct within the interstage duct causes the flow entering the deswirl vanes to be highly non-axisymmetric. This results in large part from flow separation that occurs on the discharge duct as the fluid flows around the duct. If steps are not taken to improve the uniformity of the flow entering the second-stage impeller, it has been found that the overall efficiency of the compressor suffers to a significant extent. Furthermore, if steps are not taken to minimize flow separation on the downstream side of the discharge duct, there are resultant pressures losses in the interstage duct that contribute to reduced over-all compressor efficiency.

In accordance with the invention, the uniformity of the flow into the second-stage impeller is improved in part by employing a non-axisymmetric deswirl vane arrangement that takes into account the non-axisymmetric flow conditions entering the vanes as a result of the presence of the discharge duct in the interstage duct. Flow uniformity is further improved by providing one of the deswirl vanes as a relatively thick vane that envelops the discharge duct and acts as an aerodynamic fairing around the duct so that the flow has less tendency to separate, which contributes to reduced pressure losses in the interstage duct.

FIG. 1 shows a turbocharger **10** having a two-stage compressor in accordance with one embodiment of the invention. The turbocharger **10** includes a rotary shaft **12** on one end of which a turbine wheel (not shown) is mounted. Although not illustrated, it will be understood that the turbine section of the turbocharger **10** includes a turbine housing that defines a turbine volute arranged to direct fluid to the turbine wheel. The turbine housing also defines an outlet. Exhaust gases from an engine (not shown) are fed into the turbine volute. The gases then pass through the turbine and are expanded so that the turbine wheel is rotatably driven, thus rotatably driving the shaft **12**. The expanded gases are discharged through the outlet. The turbine can be a radial turbine in which the flow enters the turbine in a generally radially inward direction; however, the invention is not limited to any particular turbine arrangement. Furthermore, the turbocharger could include means other than a turbine for driving the shaft **12**, such as an electric motor.

The shaft **12** passes through a center housing **14** of the turbocharger. The center housing connects the turbine housing (not shown) with a compressor housing assembly **28** of the turbocharger as further described below. The center

housing contains bearings **15** (only one shown in FIG. 1) for the shaft **12**. A rear end of the compressor housing assembly **28** is affixed to the center housing **14** in suitable fashion, such as with threaded fasteners **16**.

Mounted on an opposite end of the shaft **12** from the turbine is a two-stage compressor wheel comprising a first-stage impeller **24** and a second-stage impeller **26**. Surrounding the compressor wheel is the compressor housing assembly **28**. A forward portion of the compressor housing assembly defines a compressor inlet **30** leading into the first-stage impeller **24**. As further described below, a rear portion of the compressor housing assembly defines a series of flow paths for leading the pressurized fluid that exits the first-stage impeller into the second-stage impeller and for receiving and discharging the pressurized fluid that exits the second-stage impeller.

More particularly, the rear portion of the compressor housing assembly defines: a first-stage diffuser **32** that receives the fluid discharged from the first-stage impeller and diffuses (i.e., reduces the velocity and hence increases the static pressure of) the fluid; an interstage duct **34** that receives the fluid from the first-stage diffuser **32**; an arrangement **36** of deswirl vanes that receive the fluid from the interstage duct and reduce the tangential or "swirl" component of velocity of the fluid, as well as lead the fluid into the second-stage impeller **26**; and a second-stage volute **38** that surrounds the second-stage impeller and receives the fluid discharged therefrom. Although not visible in FIG. 1, and as further described below, the compressor housing assembly also defines a discharge duct that connects with the second-stage volute **38** and routes the fluid from the volute out of the compressor for feeding to the engine intake manifold or to a charge air cooler before being fed to the engine intake manifold.

The first-stage impeller **24** and second-stage impeller **26** are mounted back-to-back; that is, the downstream side of the first-stage impeller **24** is nearer the turbine than is the upstream side of the impeller, while the downstream side of the second-stage impeller **26** is farther from the turbine than is the upstream side of the impeller. As a result of this arrangement, the second-stage volute **38** is located generally concentrically within the interstage duct **34**. More specifically, the interstage duct **34** is a generally annular structure formed by an outer wall **40** that extends substantially 360 degrees about a central axis of the interstage duct (which axis generally coincides with the axis of the shaft **12**, although it does not

have to so coincide), and an inner wall **42** that extends substantially 360 degrees about the duct axis and is spaced radially inwardly from the outer wall **40**. The interstage duct **34** defined between the inner and outer walls is generally U-shaped in cross-section such that fluid entering the duct is flowing generally radially outwardly (i.e., with little or no axial component, although it does have a substantial swirl component); the duct then turns the fluid so that it is flowing generally axially (again, with substantial swirl component, but with little or no radial component), and finally turns the fluid to a generally radially inward direction (with little or no axial component, but with substantial swirl component) as the fluid enters the deswirl vane arrangement **36**. The second-stage volute **38** is located generally concentric with and radially inward of the inner wall **42** of the interstage duct. The volute **38** is delimited at its radially outward side by the inner wall **42**, and at its radially inward side by an extension **44** of the wall **42**.

The first-stage diffuser **32** is defined between the forward portion of the compressor housing assembly **28** and a stationary seal plate **46**. The seal plate separates the diffuser **32** from the second-stage volute **38** and also forms the forward wall of the second-stage diffuser. The seal plate engages the second-stage compressor wheel with a suitable rotating sealing surface **47** to prevent higher-pressure air discharged from the second-stage impeller from leaking into the lower-pressure first-stage diffuser **32**. Other types of seal arrangements can be used instead of the arrangement illustrated in FIG. 1.

With reference to FIG. 3, a duct assembly **50** of the compressor is illustrated. The duct assembly **50** forms a portion of the overall compressor housing assembly **28**. More particularly, the duct assembly **50** comprises the elements defining: the interstage duct and second-stage volute, i.e., the outer wall **40**, the inner wall **42**, and the inner extension **44** (not visible in FIG. 3); the deswirl vane arrangement **36**; and a second-stage discharge duct **52** that connects with the second-stage volute **38** (FIG. 1) for discharging air from the volute. The deswirl vane arrangement **36** includes a ring **54** of generally annular form.

With reference to FIGS. 3 and 6, the vane ring **54** comprises a plurality of deswirl vanes **56** that are spaced apart about a circumference of the ring. The vanes **56** are oriented generally radially with respect to the axis of the compressor. The vanes are cambered and arranged in such a way that the leading edges of the vanes (at the outer diameter of the ring) are directed generally in the same

direction as the swirling flow entering the vanes from the interstage duct, while the trailing edges (at the inner diameter of the ring) are directed substantially in the direction in which it is desired for the flow to exit the vanes, i.e., with little or no swirl component of velocity. The vanes thus reduce the swirl component of velocity before the flow enters the second-stage impeller.

The vanes **56** are affixed to (and can be integrally formed with) a wall **58** of generally annular form that extends generally radially with respect to the compressor axis. The axial extent of each vane **56** is oriented generally perpendicular to the wall **58**. As shown in FIG. 1, a radially inner end of the wall **58** engages the inward extension **44** of the wall of the second-stage volute **38** and an O-ring or the like is arranged therebetween for sealing this connection.

The vane ring **54** includes a vane **60** that substantially differs from all of the other vanes **56** and is located, with respect to the circumferential direction of the compressor, in alignment with the discharge duct **52** that passes through the interstage duct. As further explained below, this vane **60** forms the trailing-edge portion of a "thick" vane whose function is to guide the flow in the interstage duct around the discharge duct **52** in as aerodynamically efficient a fashion as possible. The vane **60** has a much greater thickness than that of the other vanes **56** and its maximum thickness occurs at the upstream end **61** of the vane. The thickness of the vane **60** decreases to the downstream end or trailing edge, which has a thickness substantially similar to that of the other vanes. The concave or pressure surface **60a** of the vane **60** is configured generally similarly to the convex or suction surface of the vane **56** adjacent thereto. Likewise, the convex or suction surface **60b** of the vane **60** is configured generally similarly to the concave or pressure surface of the vane **56** adjacent thereto. In the illustrated embodiment, these two vanes **56** on either side of the vane **60** are configured very differently from each other. In particular, the vane adjacent the pressure surface **60a** of the vane **60** has substantially greater camber than the vane adjacent the suction surface **60b** of the vane **60**, as best seen in FIG. 6. The remaining vanes **56** are configured so that the vane shapes progressively vary from one vane to the next so as to smoothly transition from the highly cambered vane adjacent the pressure surface **60a** to the less-cambered vane adjacent the suction surface **60b**.

With reference to FIGS. 4 and 5, the compressor housing assembly is shown with the outer wall of the interstage duct removed to reveal the leading-

edge portion of this thick vane and how it interacts with the trailing-edge portion **60**. In particular, affixed to (and possibly integrally fabricated with) the inner wall **42** of the interstage duct is a leading-edge vane portion **62**. The leading-edge vane portion **62** is configured to mate with the vane **60** of the vane ring so that collectively these structures form a "thick" vane at the location where the discharge duct from the second-stage volute passes through the interstage duct. The downstream end **63** of the leading-edge vane portion **62** has a thickness substantially matching that of the upstream end **61** of the vane **60** and is arranged so that the juncture therebetween is essentially uninterrupted and aerodynamically advantageous (e.g., no large steps in the aerodynamic surface, and substantially no gap between the mating surfaces). The upstream end **64** of the vane portion **62** has a tapered configuration defining the leading edge of the thick vane; the leading edge is located at about the entrance to the U-shaped interstage duct. The leading-edge portion **62** has a passage **66** that passes internally therethrough to allow the discharge duct to pass through this thick vane. Thus, in essence the thick vane envelops the discharge duct so that the fluid flowing through the interstage duct is guided around the discharge duct by the thick vane.

To better visualize the flow, FIG. 2 represents a three-dimensional rendering of the flow areas of the interstage duct, the second-stage volute, and the discharge duct, in "solid" form. It can be seen that the flow in the interstage duct passes around the discharge flow. The discharge flow comes out of the second-stage volute in a generally tangential direction and then turns somewhat radially outwardly and passes through the passage defined by the thick vane.

The thick vane guides the flow around the discharge duct in an aerodynamically more-advantageous way than would be the case if there were no such thick vane. Without the thick vane, and with an axisymmetric ring of deswirl vanes following the discharge duct, the flow would tend to experience substantial separation coming off the discharge duct. This would result in substantial pressure losses immediately downstream of the discharge duct and the flow conditions going into the deswirl vanes would be highly non-axisymmetric. As a result, the aerodynamic performance of neither the interstage duct nor the deswirl vanes would be particularly good, and the flow going into the second-stage impeller would still be non-axisymmetric to a substantial degree. Such non-uniform flow conditions and pressure losses associated with flow separation

would tend to impair the aerodynamic efficiency of the compressor to a significant extent.

With the use of a thick vane through which the discharge flow passes and the non-axisymmetric vane arrangement in accordance with the invention, the flow conditions entering the second-stage impeller can be more-uniform and therefore the performance of the compressor can be substantially improved.

Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.